Green Technologies for the Sustainable Metaverse and Web 3.0


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The concepts of Metaverse and Web 3.0 have surged in popularity, heralded as the "successor to the mobile Internet." Web 3.0 represents a transformative shift in the Internet landscape, emphasizing user-centric decentralization. These core principles of Web 3.0 find their fullest realization in the Metaverse, which represents the next evolutionary stage of the Internet. The Metaverse envisions a seamless and interoperable fusion of Artificial Intelligence (AI) driven virtual worlds, enriched by user-generated content (UGC), and accessible through virtual/augmented reality (VR/AR) technologies. However, the around-the-clock maintenance of the Metaverse will require intensive computation load and heavy data traffic. Therefore, network densification must continually increase while adhering to stringent data rate and latency constraints, as well as the extreme bandwidth demands imposed by Metaverse applications. Under these circumstances, it becomes imperative to explore green technologies as a means to realize the sustainable development of the Metaverse. In this Special Issue, we have received a large number of submissions, and after rounds of careful reviews, we chose 10 papers for publication after a thorough revision process by at least two independent referees.

The article, "When Metaverse Meets Computing Power Networking: An Energy-Efficient Framework for Service Placement," by L. Lin, Y. Chen, Z. Zhou, P. Li, and J. Xiong presents a computing-power-networking framework based on blockchain for the efficient placement of Metaverse services. The article focuses on optimizing service placement to minimize resource and energy consumption while meeting QoS requirements. Furthermore, a typical Metaverse scenario involving video analytics is introduced to demonstrate the proposed framework. A rigorous system model for its optimal service placement is provided, and a deep-reinforcement-learning-based method is developed to solve the optimization problem. The experimental results indicate that the framework achieves the best tradeoff between resource allocation and QoS metrics.

The article, "Service Reservation and Pricing for Green Metaverses: A Stackelberg Game Approach," by X. Huang, Y. Wu, J. Kang, J. Nie, W. Zhong, D. I. Kim, and S. Xie exploits collaborative awareness of the co-located users to achieve the green Metaverse. The article considered an augmented reality application as an example and illustrated the simultaneous processing of software components of the users, thereby eliminating redundant data transmission and processing. Moreover, an economic issue between the users and the Metaverse service provider (MSP) is studied, aiming to maximize the economic benefits of the MSP. A Stackelberg game is employed to tackle the above service reservation and pricing problem. The numerical results show demonstrated that the proposed scheme not only achieves energy savings but also fulfills individual rationality simultaneously.

The article, "Decentralized Cooperative Caching for Sustainable Metaverse via Meta Self-Supervision Learning," by X. Chen, J. Qiu, F. Zhou, H. Lu, L. Zhang, Z. Tian *et al.*, focuses on improving the content delivery quality in the interaction between the virtual and physical worlds within the Metaverse. Authors identify potential challenges posed by the heterogeneity of IoT devices and dynamic wireless environment and propose a DL solution aimed at optimizing cache resource allocation, promoting green and sustainable edge services for the Metaverse. Additionally, the article discusses DL algorithm implementations to meet reliability and latency requirements for content delivery networks.

The article, "Harnessing Web3 on Carbon Offset Market for Sustainability: Framework and A Case Study," by C. Zhou, H. Chen, S. Wang, X. Sun, A. E. Saddik, and W. Cai presents a framework for leveraging blockchain and wireless communication technologies to foster sustainable initiatives. Through an analysis of a carbon market built on the Web3 Metaverse, the study illustrates the impact of blockchain on sustainability and the unique ecosystem of the Web3 Metaverse carbon market. The article further delves into the potential influence of blockchain combined with wireless technologies on the evolving paradigm of sustainability in the Metaverse.

The article, "USTB 6G: Key Technologies and Metaverse Applications," by H. Zhang, D. Wang, S. Wu, W. Guan, and X. Liu proposes an AI-based architecture for 6G, with an AI Engine enabling network management. The article explains how the AI Engine enables intelligent network slicing and green technologies in USTB 6G. These techniques improve resource utilization and support quality-of-service for metaverse applications. Two metaverse applications are demonstrated: a virtual reality video streaming system and integrated sensing and communications. These showcase how AI enhances the performance of Metaverse applications and the sustainability of the 6G network. In summary, this timely article provides a comprehensive overview of the pivotal technologies and applications advanced by USTB 6G.

The article, "Integrated Communication and Computing Maritime Network Design for Green Metaverse," by T. Yang, Z. Cui, C. Peng, J. Wu, F. Liu, and Y. Yang integrates edge intelligence and the Metaverse to develop a green distributed network architecture. This article leverages artificial intelligence to guide edge nodes, improving data processing and transmission efficiency, thus achieving energy efficiency and network efficiency through

model segmentation and distributed routing decisions. This architecture satisfies the developmental requirements of the Metaverse while promoting sustainability. In summary, this research holds significant importance for advancing the real-world applications of Metaverse technology.

The article, "Energy-efficient Distributed Learning and Sharding Blockchain for Sustainable Metaverse," by P. Wang, L. Wei, W. Sun, H. Zhang, and Y. Zhang introduces a sustainable Metaverse architecture that combines distributed learning and sharding blockchain to address the energy efficiency challenges. To address scalability limitations, sharded blockchain and incentive-based sharding mechanisms are proposed, which achieve the parallelization of computing and storage in Metaverse while ensuring the security and vitality of distributed learning, reducing the overhead for each Metaverse device. The proposed solution improves energy efficiency as well as reduces the system data storage burden.

The article, "MetaOpera: A Cross-Metaverse Interoperability Protocol," by T. Li, C. Yang, Q. Yang, S. Lan, S. Zhou, X. Luo, H. Huang, and Z. Zheng introduces a cross-metaverse interoperability protocol. This protocol enables metaverses to interoperate with each other, regardless of their underlying technologies. The authors review state-of-the-art cross-metaverse interoperability solutions and present a number of open issues and challenges of cross-metaverse interoperability. The evaluation results show that the proposed MetaOpera is promising to serve as a fundamental infrastructure for transferring digital assets across heterogeneous metaverses.

The article, "C3Meta: A Context-Aware Cloud-Edge-End Collaboration Framework Toward Green Metaverse," by R. Wang, J. Wang, Y. Hao, L. Hu, S. A. Alqahtani, and M. Chen proposes a context-aware cloud-edge-end collaboration framework called C3Meta to establish an energy-efficient green Metaverse system based on the system condition and information flow. This article takes the smart city as a case study and a series of key technologies for handling multi-scene video streams to achieve the trade-off between detection performance and energy consumption. The C3Meta framework has the potential to contribute to a sustainable and environmentally friendly Metaverse.

The article, "Efficient Resource Allocation for Building the Metaverse with UAVs: A Quantum Collective Reinforcement Learning Approach," by Y. Wang, Y. He, F. R. Yu, B. Song, and V. C. M. Leung presents a framework that unmanned aerial vehicles (UAVs) are used to take images and choose base stations (BSs) to offload their tasks according to the Metaverse environment. This article focuses on the problem of resource allocation to efficiently utilize the limited resources of the real world and keep the Metaverse and real world frequently synchronized. To address this problem, a quantum collective reinforcement learning method is introduced to balance exploitation and exploration, while accelerating the convergence rate in the training process.

In summary, the realization of a sustainable Metaverse and the potential of Web 3.0 necessitate the integration of green technologies at every level. By implementing energy-efficient solutions, optimizing resource utilization, and promoting sustainable practices, we can ensure that the future of the digital realm aligns with environmental responsibility and resource conservation.

The above works provide numerous green technologies, modesl and methods for the sustainable development of the Metaverse and Web 3.0, ranging from environmental benefits and cost savings to improved performance and long-term viability. Embracing these technologies aligns with the growing awareness of environmental responsibility and contributes to the overall success of these digital ecosystems.

The aforementioned works present a wealth of green technologies, models, and methodologies tailored to ensure the sustainable evolution of the Metaverse and Web 3.0. These encompass a broad spectrum of advantages, encompassing economic gains, system efficiencies, enhanced performance, and security. Incorporating these innovations significantly bolsters the overall prosperity of these digital ecosystems.

In conclusion, we would like to thank all the authors who submitted their research articles to our Special Issue. We are also grateful to Professor Nirwan Ansari and Professor Dusit Niyato for understanding the importance of this timely topic and allowing us to organize this Special Issue. Finally, we would like to acknowledge the editorial team and the anonymous reviewers for their support and contributions.

Biographies

Xiaofei Wang [S'06, M'13, SM'18] (xiaofeiwang@tju.edu.cn) received his B.S. degree from Huazhong University of Science and Technology, China, and received his M.S. and Ph.D. degrees from Seoul National University, Seoul, South Korea. He was a Postdoctoral Fellow with The University of British Columbia, Vancouver, Canada, from 2014 to 2016. He is currently a Professor with the College of Intelligence and Computing, Tianjin University, Tianjin, China. Focusing on the research of edge computing, edge intelligence, and edge systems, he has published more than 160 technical papers in IEEE JSAC, TCC, ToN, TWC, IoTJ, COMST, TMM, INFOCOM, ICDCS, and so on. He has received the best paper awards of IEEE ICC, ICPADS, and in 2017, he was the recipient of the "IEEE ComSoc Fred W. Ellersick Prize."In 2022, he received the "IEEE ComSoc Asia-Pacific Outstanding Paper Award."

Mehdi Bennis [F] is currently a tenured Full Professor with the Centre for Wireless Communications, University of Oulu, Finland, and the Head of the Intelligent Connectivity and Networks/Systems Group (ICON). He has published more than 200 research papers in international conferences, journals, and book chapters. His research interests include radio resource management, game theory, and distributed AI in 5G/6G networks. He has been a recipient of several prestigious awards. He is an Editor of IEEE Transactions on Communications and a specialty Chief Editor of Data Science for Communications and Frontiers in Communications and Networks journal.

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Wei Yang Bryan Lim is an Assistant Professor at the School of Computer Science and Engineering at Nanyang Technological University (NTU), Singapore, having joined in September 2023. Between 2022 and 2023, he held the title of Wallenberg-NTU Presidential Postdoctoral Fellow. In 2022, he earned his Ph.D. from NTU under the Alibaba Ph.D. Talent Programme and was affiliated with the CityBrain team of DAMO academy during this period. His doctoral efforts earned him accolades, such as the "Most Promising Industrial Postgraduate Programme Student" award and the IEEE Technical Community on Scalable Computing (TCSC) Outstanding Ph.D. Dissertation Award. His works have been honored with Best Paper Awards, notably from the IEEE Wireless Communications and Networking Conference (WCNC) and the IEEE Asia Pacific Board. He also serves on the Technical Programme Committee for flagship conferences and is a review board member or guest editor for reputable journals like the *IEEE Transactions on Parallel and Distributed Systems* and *IEEE Wireless Communications*. In 2023, he co-edited a submission on "Requirements and Design Criteria for Sustainable Metaverse Systems" for the International Telecommunication Union (ITU). Alongside his publications in high impact journals of his field, he is the first author of two books. Additionally, he has been a visiting scholar at the KTH Royal Institute of Technology, University of Sydney, University of New South Wales, and the Singapore University of Technology and Design.